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Integrating Occupational Health and Safety (OHS) into Chemical Laboratory Learning: A Mixed-Method Study on Students' Safety Awareness and Practices

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ABSTRACT

Purpose of the study: This study aims to analyze students' occupational health and safety (OHS) awareness and practices in chemical laboratory learning and to evaluate the effectiveness of integrating OHS principles into laboratory instruction to reduce safety risks and improve compliance.

Methodology: This study employed a mixed-method approach using structured questionnaires, observation sheets, semi-structured interviews, and document analysis. Data were collected from undergraduate chemistry students. Quantitative data were analyzed using descriptive statistics, while qualitative data were analyzed through thematic analysis. Job Safety Analysis (JSA) was applied as a risk assessment tool.

Main Findings: The results showed that 78% of students received safety training, but only 34% could identify hazard symbols correctly. Compliance with safety practices was low, including fume hood usage (25%) and chemical waste disposal (10%). JSA results indicated that 19% of laboratory activities were categorized as high to extreme risk levels.

Novelty/Originality of this study: This study provides a novel integration of Job Safety Analysis (JSA) into chemical laboratory learning to systematically identify risks and improve safety practices. It also offers an evidence-based approach for embedding OHS into the curriculum, contributing to the development of a proactive laboratory safety culture.

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1. INTRODUCTION

Chemical laboratories play a crucial role in science education as they provide opportunities for students to connect theoretical knowledge with practical experience. However, laboratory environments inherently involve various hazards, including exposure to toxic chemicals, fire risks, and improper waste handling [1]-[3]. These risks necessitate the implementation of Occupational Health and Safety (OHS) principles to ensure a safe and controlled learning environment [4]-[6]. Despite the availability of safety guidelines, laboratory accidents and unsafe practices continue to occur in educational settings [7]-[9]. This indicates that the presence of safety regulations alone is not sufficient to ensure proper safety behavior among students.

In many educational institutions, OHS is often delivered as a theoretical component rather than being fully integrated into laboratory practices. Students may receive safety instructions at the beginning of a course, but these are rarely reinforced during practical activities [10]-[12]. As a result, students tend to overlook safety procedures when conducting experiments, especially under time pressure or limited supervision [13]-[15]. This situation creates a gap between students' knowledge of safety and their actual behavior in the laboratory [16]-[18]. Therefore, a more structured and practice-oriented approach to OHS integration is needed.

Previous studies have shown that students' awareness of laboratory safety does not necessarily translate into safe practices. For instance, while students may understand the importance of personal protective equipment, they may not consistently use it during experiments [19]-[21]. Similarly, knowledge of hazard symbols does not always lead to proper chemical handling or waste disposal [22]-[24]. This discrepancy highlights a critical issue in laboratory education, where cognitive understanding is not effectively transformed into behavioral compliance. Addressing this issue requires a deeper examination of how safety is taught and implemented in laboratory settings [25]-[27].

Furthermore, existing research on laboratory safety has primarily focused on assessing safety knowledge or attitudes, with limited attention given to actual safety practices and risk identification [28]-[30]. Few studies have incorporated systematic risk assessment tools, such as Job Safety Analysis (JSA), into educational contexts [31]-[33]. The absence of such tools limits the ability to identify high-risk activities and implement targeted preventive measures. Consequently, there is a need for research that combines safety awareness, behavioral observation, and structured risk analysis [34]-[36]. This integrated approach can provide a more comprehensive understanding of laboratory safety.

The present study addresses this gap by integrating OHS principles directly into chemical laboratory learning using a mixed-method approach [37], [38]. It combines quantitative assessment of students' safety awareness with qualitative evaluation of their actual practices during laboratory activities. In addition, the application of Job Safety Analysis (JSA) allows for systematic identification and classification of laboratory risks [39], [40]. This approach not only evaluates students' behavior but also provides practical insights into improving laboratory safety management. Therefore, the study contributes to bridging the gap between theoretical knowledge and practical implementation of safety.

The novelty of this study lies in the integration of JSA within the context of chemical laboratory education, which has rarely been explored in previous research. By embedding risk assessment into the learning process, students are encouraged to actively identify hazards and implement preventive measures [41], [42]. This approach shifts the focus from passive learning to active engagement in safety practices. Moreover, the study proposes a model for integrating OHS into the curriculum in a structured and sustainable manner. This innovation is expected to enhance both students' safety awareness and their practical competencies.

Based on these considerations, this study aims to analyze students' awareness of OHS, evaluate their safety practices, identify laboratory risks using JSA, and examine the effectiveness of OHS integration in chemical laboratory learning. The findings of this study are expected to provide valuable insights for educators and institutions in improving laboratory safety education. In addition, the results may serve as a basis for developing more effective safety training programs and policies. Ultimately, this study seeks to contribute to the development of a proactive safety culture in educational laboratories. Such a culture is essential for minimizing risks and ensuring a safe learning environment for all laboratory users.

2. RESEARCH METHOD

2.1. Research Design

This study employed a mixed-method research design to comprehensively examine students' occupational health and safety (OHS) awareness and practices in chemical laboratory learning. The integration of quantitative and qualitative approaches allows for a more holistic understanding of both measurable outcomes and contextual factors influencing safety behavior [43], [44]. The quantitative component focused on assessing students' knowledge and awareness of laboratory safety using structured instruments. Meanwhile, the qualitative component explored students' actual practices, perceptions, and challenges through observations and interviews [45], [46]. This design was selected to bridge the gap between reported awareness and observed behavior in laboratory settings.

Furthermore, the mixed-method design follows a convergent parallel approach in which quantitative and qualitative data were collected simultaneously. Both types of data were analyzed independently and then integrated to provide a comprehensive interpretation of the findings [47], [48]. This approach enables the validation of results through triangulation, increasing the reliability and credibility of the study. The use of multiple data sources also strengthens the depth of analysis, particularly in identifying inconsistencies between knowledge and practice. Therefore, this design is considered appropriate for investigating complex phenomena such as laboratory safety behavior.

2.2. Population and Sample

The population of this study consisted of undergraduate students enrolled in chemistry laboratory courses at a higher education institution. These students were selected because they are directly involved in laboratory activities that require adherence to safety protocols. The population represents individuals with varying levels of laboratory experience and safety training. This diversity allows for a more comprehensive analysis of safety awareness and practices [49], [50]. Therefore, the population is relevant to the objectives of this study.

The sample was determined using purposive sampling based on specific criteria related to students' participation in laboratory activities. A total of 70 students were selected as participants, ensuring that all respondents had prior experience in conducting chemical experiments. The sampling criteria included active involvement in laboratory sessions and prior exposure to safety training [51], [52]. This approach ensures that the data collected are directly relevant to the research focus. Consequently, the selected sample is expected to provide meaningful insights into laboratory safety practices.

2.3. Research Instruments

The study utilized several research instruments to collect both quantitative and qualitative data. A structured questionnaire was developed to assess students' knowledge and awareness of occupational health and safety in chemical laboratories [1], [53]. The questionnaire included items related to hazard identification, use of personal protective equipment, and understanding of safety procedures. In addition, an observation sheet was designed to evaluate students' actual safety practices during laboratory activities. These instruments were developed based on established OHS standards and previous research in laboratory safety.

To complement the quantitative data, semi-structured interview guidelines were used to explore students' perceptions and experiences regarding laboratory safety. Document analysis was also conducted on laboratory manuals and safety guidelines to assess the extent of OHS integration in instructional materials. All instruments were validated through expert judgment to ensure content validity and relevance [54], [55]. Reliability testing was conducted for the questionnaire to ensure consistency of responses. Therefore, the combination of these instruments enables comprehensive data collection aligned with the research objectives.

2.4. Data Collection Techniques

Data collection was conducted using multiple techniques to capture a comprehensive picture of students' safety awareness and practices. The questionnaire was administered to students to obtain quantitative data on their knowledge and awareness of laboratory safety. Observations were carried out during laboratory sessions to assess students' actual behavior in applying safety procedures [56], [57]. These observations focused on key aspects such as the use of personal protective equipment, handling of chemicals, and waste disposal practices. This approach allows for direct comparison between reported knowledge and observed behavior.

In addition to questionnaires and observations, interviews were conducted with selected participants to gain deeper insights into their perceptions and challenges related to OHS implementation. Document analysis was also performed to evaluate the integration of safety guidelines in laboratory instruction [58], [59]. Data collection was conducted over a specific period during active laboratory sessions to ensure the authenticity of observed practices. All data collection procedures were carried out systematically to maintain consistency and accuracy. Thus, the combination of these techniques ensures data triangulation and enhances the validity of the findings.

2.5. Data Analysis Techniques

The data analysis process involved both quantitative and qualitative techniques to ensure comprehensive interpretation of the findings. Quantitative data obtained from questionnaires were analyzed using descriptive statistics, including percentages and frequencies [60], [61]. These analyses were used to measure students' levels of safety awareness and knowledge. The results were presented in tabular and graphical forms to facilitate interpretation. This approach provides a clear overview of the distribution of responses among participants.

Qualitative data from observations and interviews were analyzed using thematic analysis to identify patterns and recurring themes related to safety practices. The analysis process included data reduction, data categorization, and interpretation of findings. In addition, Job Safety Analysis (JSA) was applied to identify potential hazards and classify risk levels in laboratory activities [62], [63]. The integration of quantitative and qualitative results was conducted to provide a comprehensive understanding of the research problem. Therefore, this analytical approach ensures that the findings are both robust and meaningful.

2.6. Research Procedures

The research procedures were carried out in several systematic stages to ensure the validity and reliability of the study. The first stage involved preliminary observation and identification of problems related to laboratory safety practices [64], [65]. This was followed by the development and validation of research instruments. After that, data collection was conducted through questionnaires, observations, interviews, and document analysis. These steps were designed to ensure that all relevant data were collected in a structured manner.

The next stage involved data analysis and interpretation of findings based on both quantitative and qualitative data. The results were then integrated to draw comprehensive conclusions regarding students' safety awareness and practices. Finally, recommendations were formulated based on the findings to improve the integration of OHS in chemical laboratory learning. Each stage of the research was carefully planned and executed to maintain methodological rigor [66], [67]. Thus, the overall procedure ensures that the study produces reliable and valid results. The flowchart of this research procedure can be seen in Figure 1.

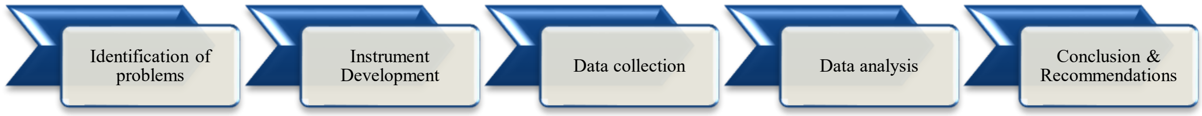

Figure 1. Research Procedures

3. RESULTS AND DISCUSSION

3.1. Students' Occupational Health and Safety Awareness

The quantitative analysis of students' occupational health and safety (OHS) awareness was conducted using questionnaire data. The results indicate that although most students have been exposed to safety training, their conceptual understanding remains limited. The descriptive statistics show that 78% of students reported having received safety training, with a mean awareness score of 2.9 (moderate level). However, only 34% of students were able to correctly identify chemical hazard symbols, while knowledge of chemical storage (33%) and handling (34%) remained low. These findings suggest that students' awareness is still superficial and not deeply internalized.

Table 1. Students' OHS Awareness Level

Indicator	Percentage (%)	Mean Score
Received safety training	78%	3.5
Understanding of hazard symbols	34%	2.6
Knowledge of chemical storage	33%	2.5
Knowledge of chemical handling	34%	2.6

The qualitative findings support these results, revealing two main themes: *limited conceptual understanding* and *passive learning behavior*. Students reported that safety training was often delivered in a lecture format without practical reinforcement. One participant stated, *"We were told about safety rules at the beginning, but we rarely revisit them during experiments."* This indicates that safety knowledge is not continuously reinforced throughout laboratory activities. Another student mentioned, *"Sometimes we memorize the symbols for exams, but we do not really understand their meaning during practice."* These findings confirm that students' awareness is largely procedural rather than conceptual.

The integration of quantitative and qualitative data indicates a clear gap between exposure and understanding. While students are formally introduced to OHS concepts, the lack of active engagement limits their ability to internalize safety knowledge. This finding aligns with constructivist learning theory, which emphasizes the importance of active participation in knowledge construction [68], [69]. Previous studies have also reported similar issues, where safety instruction is often delivered as theoretical content without meaningful application [70]. Therefore, enhancing students' awareness requires more interactive and context-based learning approaches.

3.2. Students' Safety Practices in Laboratory Activities

Observation data were used to evaluate students' actual safety practices during laboratory sessions. The results indicate that compliance with safety procedures is generally low, particularly in critical aspects of laboratory work. The mean score for overall safety practice was 2.7 (moderate to low level). As shown in Table 2, only 25% of students properly used the fume hood, and only 10% followed correct chemical waste disposal procedures. This suggests that students' safety behavior is inconsistent and requires improvement.

Table 2. Students' Safety Practices

Safety Practice	Compliance (%)	Mean Score
Proper use of PPE	60%	3.0
Use of fume hood	25%	2.4
Proper chemical waste disposal	10%	2.2

Qualitative findings reveal three major themes: *lack of supervision*, *time pressure*, and *low risk perception*. Students admitted that they often neglect safety procedures when focusing on completing experiments. One participant stated, *"We know we should use the fume hood, but sometimes it takes too much time, so we skip it."* Another student mentioned, *"There is no strict supervision, so we just follow what others do."* These responses indicate that environmental and situational factors significantly influence students' behavior.

The integration of findings shows that low compliance is not solely due to lack of knowledge but also influenced by behavioral and contextual factors. This supports behavioral safety theory, which emphasizes the role of reinforcement and environmental conditions in shaping behavior. Previous research has also shown that supervision and feedback are critical in ensuring compliance with safety procedures [71]. Therefore, improving safety practices requires not only knowledge enhancement but also consistent monitoring and behavioral reinforcement strategies.

3.3. Risk Identification Using Job Safety Analysis (JSA)

The Job Safety Analysis (JSA) was conducted to systematically identify hazards and assess risk levels in laboratory activities. The results show that laboratory tasks involve varying levels of risk, with a significant proportion categorized as medium to high risk. As presented in Table 3, 51% of activities fall into the medium-risk category, while 19% are classified as high to extreme risk. This indicates that laboratory activities inherently involve potential hazards that must be carefully managed. The findings highlight the importance of implementing structured risk assessment in laboratory learning.

Table 3. Risk Level Classification Based on JSA

Risk Level	Percentage (%)
Low Risk	30%
Medium Risk	51%
High Risk	15%
Extreme Risk	4%

A more detailed JSA analysis identified specific high-risk activities, such as acid dilution and heating volatile substances. For example, acid dilution presents a splash hazard that can cause chemical burns if not handled properly. The recommended control measures include the use of PPE, proper handling techniques, and the use of fume hoods. Similarly, heating volatile substances poses a risk of explosion if conducted without adequate ventilation. These findings demonstrate the practical value of JSA in identifying and mitigating laboratory risks.

The application of JSA in this study provides a structured approach to risk identification and management. This aligns with risk management theory, which emphasizes proactive identification and control of hazards. Previous studies have shown that integrating risk assessment tools into training programs significantly improves safety outcomes [72], [73]. By involving students in the JSA process, they become more aware of potential hazards and learn how to manage risks effectively. Therefore, JSA serves as both an analytical tool and a learning strategy in laboratory safety education.

3.4. Discussion: Integration of OHS in Laboratory Learning

The overall findings of this study reveal a significant gap between students' safety awareness and their actual practices. While students have basic knowledge of OHS, their understanding is limited and not effectively translated into behavior. This gap is influenced by both cognitive and contextual factors, including passive learning methods and lack of supervision. The integration of quantitative and qualitative findings highlights the complexity of safety behavior in laboratory settings. Therefore, addressing this issue requires a comprehensive and integrated approach.

The integration of OHS into laboratory learning has been shown to improve both awareness and practices. By embedding safety principles into laboratory activities, students are encouraged to actively engage in identifying hazards and applying safety procedures [74], [75]. The use of JSA further enhances this process by providing a structured framework for risk analysis. This approach aligns with experiential learning theory, which emphasizes learning through direct experience and reflection. Previous studies have also demonstrated that active learning strategies significantly improve safety behavior.

Furthermore, the findings emphasize the importance of developing a strong safety culture in educational laboratories. Safety culture involves shared values, attitudes, and behaviors related to safety practices. Continuous training, supervision, and the use of visual aids are essential in reinforcing this culture [76], [77]. The integration of OHS into the curriculum ensures that safety becomes an integral part of the learning process. Ultimately, this approach contributes to creating a safer and more effective laboratory learning environment.

The findings of this study have important implications for both educational practice and policy in chemical laboratory learning. The integration of Occupational Health and Safety (OHS) into laboratory instruction should not be limited to initial training sessions but must be embedded continuously throughout the learning process. Educators are encouraged to adopt active and experiential learning approaches, such as the implementation of Job Safety Analysis (JSA), to enhance students' engagement and understanding of safety practices. In addition, institutions should develop structured safety programs that include regular monitoring, supervision, and the use of visual safety aids to reinforce safe behavior. These efforts are essential for fostering a proactive safety culture and minimizing risks in laboratory environments.

However, this study has several limitations that should be considered when interpreting the findings. The sample size was limited to students from a single institution, which may affect the generalizability of the results to other educational contexts. In addition, the study relied on descriptive statistical analysis, which may not fully capture the complexity of relationships between variables. Future research is recommended to involve a larger and more diverse sample, as well as to apply more advanced statistical techniques to examine causal relationships. Furthermore, the integration of digital technologies, such as virtual laboratory simulations and smart safety monitoring systems, should be explored to enhance the effectiveness of OHS implementation in laboratory learning.

4. CONCLUSION

This study concludes that students' occupational health and safety (OHS) awareness in chemical laboratories is at a moderate level but remains largely procedural and not deeply understood. Students' safety practices are generally low and inconsistent, indicating a clear gap between awareness and actual behavior. The application of Job Safety Analysis (JSA) successfully identified that a significant portion of laboratory activities fall into medium to high-risk categories. Furthermore, integrating OHS into laboratory learning, supported by JSA, is effective in improving students' awareness, safety practices, and risk management skills. Therefore, structured and practice-oriented OHS integration is essential for developing a proactive laboratory safety culture.

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AUTHOR CONTRIBUTIONS

Conceptualization, HAD and JBK; Methodology, HAD; Software, HAD; Validation, HAD, JBK and FKRK; Formal Analysis, HAD; Investigation, HAD; Resources, JBK; Data Curation, HAD; Writing – Original Draft Preparation, HAD; Writing – Review & Editing, JBK and FKRK; Visualization, HAD; Supervision, FKRK; Project Administration, JBK; Funding Acquisition, FKRK.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

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